



Planetary Geoscience

For many years, planetary science has been taught as part of the astronomy curriculum, from a very physics-based perspective, and from the framework of a tour of the Solar System – body by body. Over the past decades, however, spacecraft exploration and related laboratory research on extraterrestrial materials have given us a new understanding of planets and how they are shaped by geologic processes.

Based on a course taught at the University of Tennessee, Knoxville, this is the first textbook to focus on geologic processes, adopting a comparative approach that demonstrates the similarities and differences between planets, and the reasons for these. Profusely illustrated, and with a wealth of pedagogical features, this book provides an ideal capstone course for geoscience majors – bringing together aspects of mineralogy, petrology, geochemistry, volcanology, sedimentology, geomorphology, tectonics, geophysics, and remote sensing.

Harry Y. McSween, Jr. is Chancellor's Professor Emeritus of Planetary Geoscience at the University of Tennessee, Knoxville. He holds degrees from The Citadel (BS), the University of Georgia (MS), and Harvard University (PhD). His research focuses on meteorites and has resulted in the publication of hundreds of scientific papers on the subject. He has also authored three popular books on planetary science, as well as textbooks in geochemistry and cosmochemistry. He has served as co-investigator for many NASA spacecraft missions, including Mars Pathfinder, Mars Exploration Rovers, Mars Odyssey orbiter, and Dawn asteroid orbiter. McSween has been elected President of the Meteoritical Society and of the Geological Society of America, and is a fellow of the American Academy of Arts and Sciences. He is the recipient of the Leonard Medal (Meteoritical Society), the J. Lawrence Smith Medal (US National Academy of Sciences), and the Whipple Award (American Geophysical Union), and is the namesake for asteroid 5223 McSween.

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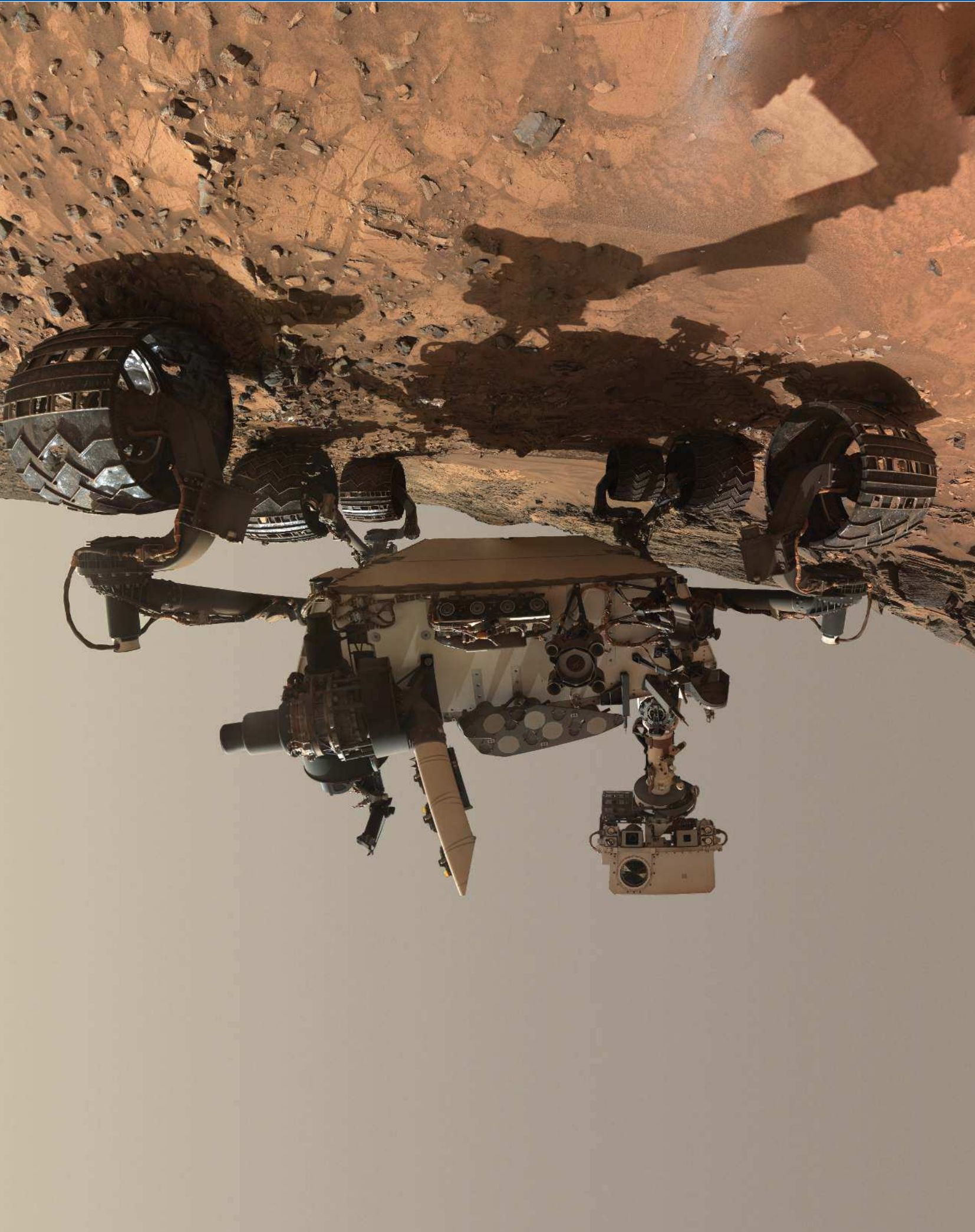
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Harry Y. McSween, Jr , Jeffrey E. Moersch , Devon M. Burr , William M. Dunne , Joshua P. Emery , Linda C. Kah , Molly C. McCanta
Frontmatter

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Brief Contents



Preface: Geologic Processes in the Solar System	xv	11	
1			
Exploring the Solar System	3		Impact Cratering as a Geologic Process 191
2		12	
Toolkits for the Planetary Geoscientist: Spectroscopy and Imaging	19		Planetary Atmospheres, Oceans, and Ices 211
3		13	
More Toolkits for the Planetary Geoscientist: Chronology, Mapping, Geophysics, and Laboratory Analysis	49		Planetary Aeolian Processes and Landforms 227
4		14	
Solar System Raw Materials	67		Planetary Fluvial and Lacustrine Landforms: Products of Liquid Flow 243
5		15	
Assembling Planetesimals and Planets	81		Physical and Chemical Changes: Weathering, Sedimentology, Metamorphism, and Mass Wasting 259
6		16	
Planetary Heating and Differentiation	101		Astrobiology: A Planetary Perspective on Life 277
7		17	
Unseen Planetary Interiors	115		Integrated Planetary Geoscience: A Case Study (Mars) 295
8			Epilogue: Geologic Processes in Other Solar Systems? 316
Planetary Geodynamics	129		Glossary 320
9			Index 327
Planetary Structures and Tectonics	151		
10			
Planetary Igneous Activity	171		

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Frontmatter

[More Information](#)

Contents



Preface: Geologic Processes in the Solar System xv

1

Exploring the Solar System 3

1.1	Planetary Exploration and Explorers	3
1.2	Poking Around the Neighborhood: The Terrestrial Planets	3
1.2.1	Earth's Moon	5
1.2.2	Mars	7
1.2.3	Venus	7
1.2.4	Mercury	8
1.3	Xenoplanets: Gas Giants and Ice Giants	8
1.3.1	Jupiter	9
1.3.2	Saturn	9
1.3.3	Uranus	9
1.3.4	Neptune	9
1.4	The Most Interesting Moons	10
1.4.1	Galilean Moons of Jupiter	10
1.4.2	Titan and Enceladus of Saturn	11
1.4.3	Triton of Neptune	11
1.5	Small Bodies, Big Rewards	12
1.5.1	Dwarf Planets: Ceres and Pluto	12
1.5.2	Asteroids	13
1.5.3	Comets	13
1.6	A Few Notes on Orbital Dynamics	14
	Summary	15
	Review Questions	16
	Suggestion for Further Reading	16
	Reference	16

2

Toolkits for the Planetary Geoscientist: Spectroscopy and Imaging 19

2.1	Sensing Remotely	19
2.2	The Electromagnetic Spectrum	20
2.3	Blackbody Emission	21
2.4	Emissivity and Reflectance Spectra	22
2.5	Making Spectra Useful: Information from Different Regions of the Electromagnetic Spectrum	24
2.5.1	Gamma Rays	24
2.5.2	X-rays and Ultraviolet Photons	24
2.5.3	Visible and Near-Infrared Photons	25

2.5.4	Thermal Infrared Photons	25
2.5.5	Microwave and Radio Photons	25
2.6	Example Spectra	26
2.6.1	Visible/Near-Infrared Reflectance Spectra of Iron-Bearing Minerals	26
2.6.2	Vibrational Features in Near-Infrared Reflectance Spectra	27
2.6.3	Vibrational Features in Thermal Infrared Emissivity Spectra	28
2.6.4	Complicating Factors in Making Spectral Identifications	28
2.7	Remote Sensing Instrumentation and Observational Considerations	29
2.7.1	Framing Cameras	29
2.7.2	Scanning Systems	31
2.7.3	Hyperspectral Push-Broom Imagers	32
2.7.4	Band Placement and Atmospheric Transmission	32
2.7.5	Other Instrumental/Experimental Considerations	34
2.8	Analysis of Multi- and Hyperspectral Image Cubes	37
2.9	Ground Truthing	38
2.10	Nuclear Remote Sensing	40
2.10.1	Gamma Rays	40
2.10.2	Neutrons	42
2.10.3	Observational Considerations in Nuclear Remote Sensing	43
2.11	Radar Remote Sensing	43
	Summary	45
	Review Questions	46
	Suggestions for Further Reading	46
	References	46

3

More Toolkits for the Planetary Geoscientist: Chronology, Mapping, Geophysics, and Laboratory Analysis 49

3.1	Geochronology	49
3.1.1	Planetary Stratigraphy	49
3.1.2	Crater Size–Frequency Distribution as a Chronometer	50
3.1.3	Radioactive Isotopes as a Chronometer	51

3.2	Geologic Mapping	53	5.3	Solar System Chronology, by the Numbers	84
3.2.1	Imagery	54	5.4	Recipes for Planets	86
3.2.2	Definition of Map Units	55	5.4.1	The Terrestrial Planets	86
3.2.3	Relative Age Determination of Units	57	5.4.2	The Giant Planets	88
3.2.4	Rock (or Ice) Units and Rock (or Ice)-Time Units	58	5.5	The Leftovers: Asteroids and Comets	88
3.2.5	Mapping Tectonic Structures	58	5.5.1	Asteroids	88
3.3	Geophysical Methods	58	5.5.2	Comets	90
3.3.1	Topography	59	5.5.3	A Hole in the Solar Nebula?	90
3.3.2	Gravity	59	5.6	Whence Earth's Moon?	95
3.3.3	Magnetics	60	5.6.1	Origin of the Moon	95
3.3.4	Seismicity	60	5.6.2	Orbital Scrambling	95
3.3.5	Radiometry	60	Summary		96
3.4	Analysis of Planetary Materials	61	Review Questions		97
3.4.1	Available Extraterrestrial Samples	61	Suggestions for Further Reading		97
3.4.2	Laboratory Analysis Techniques	61	References		97
3.4.3	Geochemical, Mineralogical, and Geophysical Instruments Adapted for Landed Operations	63			
Summary		63	6	Planetary Heating and Differentiation	101
Review Questions		63	6.1	Too Hot to Handle	101
Suggestions for Further Reading		64	6.2	Heat Sources	102
References		64	6.2.1	Accretion and Impacts	102
			6.2.2	Radioactive Decay	102
			6.2.3	Core Segregation and Core Crystallization	103
4			6.2.4	Tidal Forces	103
Solar System Raw Materials	67		6.3	Magma Oceanography	103
4.1	Adding Cosmo to Chemistry	67	6.4	Differentiation of Rocky Planets and Planetesimals	105
4.2	Origin of the Elements	67	6.4.1	Getting to the Heart of the Matter: Cores	105
4.2.1	Stellar (and Solar) Formation and Evolution	67	6.4.2	Going Up: Crusts	106
4.2.2	Nucleosynthesis, Slow and Fast	69	6.4.3	What's Left: Mantles	108
4.3	Composition of the Solar System	69	6.4.4	Another View: Partial Differentiation	109
4.4	Minerals, Ices, and Organic Matter	73	6.5	Differentiation of the Giant Planets	109
4.4.1	Condensation of Minerals	73	6.6	Hot, and Then It's Not	110
4.4.2	Making Organic Molecules	75	Summary		110
4.4.3	Condensation of Ices: The Only Stuff Left	75	Review Questions		111
4.5	Chemical Fractionations in the Solar Nebula	77	Suggestions for Further Reading		111
4.5.1	Element Fractionations	77	References		111
4.5.2	Isotope Fractionations	78			
Summary		79	7	Unseen Planetary Interiors	115
Review Questions		79	7.1	Hardened Hearts	115
Suggestions for Further Reading		79	7.2	Inside the Planet We Know Best	115
References		79	7.2.1	Seismology	115
			7.2.2	Samples from the Mantle	117
			7.2.3	High-Pressure Experiments	117
			7.2.4	Seismic Tomography and Convection	118
5					
Assembling Planetesimals and Planets	81				
5.1	Dust to Disk	81			
5.2	Stages of Accretion	81			
5.2.1	Evolution of Stellar Objects	81			
5.2.2	Planet Formation	82			

7.3	Inside Other Rocky Planets	119
7.3.1	Seismology	119
7.3.2	Mean Density	120
7.3.3	Moment of Inertia	121
7.3.4	Gravity and Tides	121
7.3.5	Models of Planetary Interiors	121
7.3.6	Timing of Planetary Differentiation	122
7.4	Interiors of the Giant Planets and Icy Moons	123
7.4.1	Jupiter and Saturn	123
7.4.2	Uranus and Neptune	124
7.4.3	Icy Moons	124
7.5	Evolution of Planetary Interiors	124
	Summary	125
	Review Questions	125
	Suggestions for Further Reading	125
	References	126

8

	Planetary Geodynamics	129
8.1	Motions in Planetary Interiors	129
8.2	Geologic Stresses and Deformations	130
8.2.1	Balancing Act: Stress Equilibrium	130
8.2.2	What Exactly Is Strain?	130
8.2.3	Relating Stress and Strain	131
8.3	The Weight of the World: Isostasy and Flexure	132
8.3.1	Isostasy	133
8.3.2	Flexure	134
8.4	The Pull of Gravity	136
8.4.1	The Geoid	136
8.4.2	Gravity Anomalies	138
8.4.3	Assessing the Compensation State	138
8.5	Conductive Heat Flow	139
8.5.1	Fourier's Law and Heat Diffusion	139
8.5.2	Surface Heat Flux and Temperature Profiles	140
8.5.3	Solar Heating	141
8.5.4	Thermal Stresses	142
8.6	Going with the Flow: Fluid Mechanics	142
8.6.1	Conservation Laws	143
8.6.2	Relaxing Topography	143
8.6.3	Convection	144
8.7	Rheology	144
8.7.1	Visco-Elastic Rheology	146
8.7.2	Non-Newtonian Rheology	146
	Summary	147
	Review Questions	147
	Suggestions for Further Reading	148
	References	148

9

	Planetary Structures and Tectonics	151
9.1	Active-Lid versus Stagnant-Lid Planets and Satellites	151
9.2	Lithospheric Materials, Deformation Behaviors, and Strengths	152
9.2.1	Materials	152
9.2.2	Deformation Behaviors	153
9.2.3	Lithospheric Strength as a Function of Depth	153
9.3	Energy Sources and Driving Stresses	154
9.3.1	Thermal Sources	154
9.3.2	Density Inversion Sources	155
9.3.3	Tidal Sources	155
9.3.4	True Polar Wander as a Source	157
9.4	Structures and Tectonics for Stagnant Lids	157
9.4.1	Simple Stagnant Lids (Mercury, Callisto)	157
9.4.2	A Loaded Stagnant Lid (Mars)	159
9.5	Structures and Tectonics for Active Lids	161
9.5.1	Active Lid with Plate Tectonics (Earth)	161
9.5.2	Active Lid without Plate Tectonics (Europa)	163
9.5.3	Partially Active Lid without Plate Tectonics (Enceladus)	165
9.6	Stagnant Lid Possibly Active in the Past? (Venus)	167
	Summary	168
	Review Questions	168
	Suggestion for Further Reading	169
	References	169

10

	Planetary Igneous Activity	171
10.1	Magmas, Everywhere You Look	171
10.2	Magmatic Activity on the Planet We Know Best	171
10.3	Planetary Volcanism and Eruptive Styles	173
10.3.1	Moon	173
10.3.2	Mercury	174
10.3.3	Venus	174
10.3.4	Mars	176
10.3.5	Io	176
10.3.6	Comparisons of Eruptive Style	177
10.4	Planetary Igneous Petrology and Geochemistry	178
10.4.1	Moon	178
10.4.2	Mars	178

10.4.3 Asteroid Vesta	182	12.3 Physics of Planetary Atmospheres	213
10.4.4 Bodies without Samples	183	12.3.1 Atmospheric Structures	213
10.5 Petrologic Comparisons and Magmatic Evolution	184	12.3.2 Cloud Formation	214
10.5.1 Planetary Igneous Rocks	184	12.3.3 Atmospheres in Motion	215
10.5.2 Planetary Magmatic Evolution through Time	186	12.4 Sloshing Oceans, Seas, and Lakes	215
Summary	186	12.4.1 Oceans on Earth and Perhaps Ancient Mars	216
Review Questions	186	12.4.2 Titan's Hydrocarbon Lakes	217
Suggestions for Further Reading	187	12.4.3 Subsurface Seas on Other Worlds	217
References	187	12.5 Frozen Volatiles	218
		12.5.1 Surface Ice: Polar Ice Caps	218
		12.5.2 Surface Ice: Glaciers	219
		12.5.3 Subsurface Ice: Permafrost	219
		12.5.4 Worlds with Icy Crusts	220
		12.6 Origin and Evolution of Planetary Volatiles	221
		12.6.1 Sources of Volatiles	221
		12.6.2 Liquid Condensation	221
		12.6.3 How Atmospheres Evolve	222
		12.7 Geochemical Cycles and Their Consequences	222
		12.7.1 Earth's Carbon Cycle	222
		12.7.2 Greenhouse Warming: Now and Then, Here and There	223
		Summary	223
		Review Questions	224
		Suggestions for Further Reading	224
		References	224
11		13	
Impact Cratering as a Geologic Process	191	Planetary Aeolian Processes and Landforms	227
11.1 Terrestrial Craters: A Little History	191	13.1 Bringing the Atmosphere Down to the Surface (and Why We Care)	227
11.2 Crater Morphologies: Simple and Complex	191	13.2 The Near-Surface Wind Profile	229
11.3 Cratering Mechanics	194	13.3 The Physics of Particle Entrainment	230
11.3.1 Energy and Shock Waves	194	13.3.1 Force (Torque) Balance: The Conditions for Entrainment	230
11.3.2 Stages of Crater Formation	194	13.3.2 Entrainment by Fluid and by Impact	231
11.4 Geology of Impact Craters	197	13.4 Aeolian Transport of Sediment	231
11.4.1 Shatter Cones Formed at the Contact/Compression Stage	197	13.4.1 Terminal Velocities for Sand versus Dust	231
11.4.2 Breccias Formed at the Excavation Stage	199	13.4.2 Transport Mechanisms	233
11.4.3 Structures Formed at the Excavation Stage	199	13.5 Aeolian Deposition and Planetary Landforms	234
11.4.4 Structures Formed at the Modification Stage	200	13.5.1 Depositional Landforms for Sand	234
11.5 Shock Metamorphism	200	13.5.2 Depositional Landforms for Dust	237
11.5.1 Changes in Shocked Terrestrial Rocks	200	13.6 Planetary Erosional Landforms	237
11.5.2 Shock in Extraterrestrial Rocks	203	13.6.1 Yardangs	237
11.6 Role of Craters in Planetary and Terrestrial Geology	203	13.6.2 Ventifacts	238
11.7 A Threat to Life and Civilization	204		
Summary	206		
Review Questions	207		
Suggestions for Further Reading	207		
References	208		
12			
Planetary Atmospheres, Oceans, and Ices	211		
12.1 Planetary Volatile Reservoirs and Dynamics	211		
12.2 Chemistry of Planetary Atmospheres	211		
12.2.1 Atmospheric Pressures and Molecular Abundances	212		
12.2.2 A Special Role for Noble Gases	213		

13.7 Combined or Ambiguous Planetary Landforms	238	15.2.1 The Lunar Regolith	260
13.7.1 Stone Pavements	238	15.2.2 Asteroid Regoliths	262
13.7.2 Wind Streaks	239	15.2.3 The Martian Regolith	263
Summary	239	15.3 Chemical Weathering and Aqueous Alteration	264
Review Questions	240	15.3.1 Chemical Weathering on Mars	264
Suggestions for Further Reading	240	15.3.2 Asteroids: Cosmic or Cosmuck?	265
References	240	15.4 Sedimentary Petrology on Other Worlds	267
14		15.5 Metamorphism	268
Planetary Fluvial and Lacustrine Landforms: Products of Liquid Flow	243	15.5.1 Thermal Metamorphism on the Surface of Venus	268
14.1 Volatile Landscapes	243	15.5.2 Thermal Metamorphism in the Interiors of Asteroids	268
14.2 Liquid: Falling Down, Soaking In, Flowing Over, Flowing Through, Coming Out	244	15.5.3 Hydrothermal Metamorphism on Mars	268
14.2.1 How Liquids Interact with Landscapes	244	15.6 Mass Wasting	269
14.2.2 The Drainage Basin as the Fundamental Unit in Hydrology	245	Summary	272
14.3 Processes that Channelize the Flow of Liquid	245	Review Questions	272
14.3.1 Flow Velocity Profile	246	Suggestions for Further Reading	273
14.3.2 Entrainment	247	References	273
14.3.3 Transport Mechanisms of Fluvial Sediment: Three Regimes	248	16	
14.3.4 Fluvial Bedforms	249	Astrobiology: A Planetary Perspective on Life	277
14.3.5 Fluvial Erosion	249	16.1 The Diversity of Life	277
14.4 Channelized Flow of Liquid: Landscape Results	250	16.1.1 Reconstructing the Tree of Life	277
14.4.1 Fluvial Channels	250	16.1.2 Complexities in the Tree of Life	278
14.4.2 Channel Drainage Networks	251	16.1.3 The Last Universal Common Ancestor	280
14.5 Deposition from Channelized Flow	251	16.2 The Chemistry of Life	280
14.5.1 Subaerial Deposition: Fans and Bajadas	251	16.2.1 CHNOPS and the Cosmos	280
14.5.2 Subaqueous Deposition: Deltas	254	16.2.2 Water, the Elixir of Life	282
14.6 Large Bodies of Standing Liquids	254	16.3 Emergence of Life on Earth	283
14.6.1 Marine and Lacustrine Morphologies on Mars	255	16.4 Earth's Early Biosphere	284
14.6.2 Hydrocarbon Lakes and Seas on Titan	255	16.4.1 Recognizing Early Life	285
Summary	255	16.4.2 The Chemical Record of Life	286
Review Questions	256	16.5 Life Beyond Earth	287
Suggestions for Further Reading	256	16.5.1 Habitable Zones	287
References	256	16.5.2 Life in a Martian Meteorite?	288
		16.5.3 The Ongoing Search for Organic Matter on Mars	290
		Summary	290
		Review Questions	290
		Suggestions for Further Reading	291
		References	291
15		17	
Physical and Chemical Changes: Weathering, Sedimentology, Metamorphism, and Mass Wasting	259	Integrated Planetary Geoscience: A Case Study (Mars)	295
15.1 Petrologic Changes and the Rock Cycle	259	17.1 Geologic Exploration of a Planet	295
15.2 Regoliths: Physical Weathering	260	17.2 Planetary Reconnaissance and a Global Geologic Map	295

17.2.1 Global Physiography and Structure	295	17.5.3 Hesperian Period/System	310
17.2.2 Global Remote Sensing	296	17.5.4 Amazonian Period/System	311
17.2.3 Global Stratigraphic Timescale and Geologic Map	296	Summary	312
17.3 Regional Geology from Orbit and Surface Exploration by Rovers	296	Review Questions	312
17.3.1 Gusev Crater	296	Suggestions for Further Reading	312
17.3.2 Meridiani Planum	300	References	312
17.3.3 Gale Crater	302	Epilogue: Geologic Processes in Other Solar Systems?	316
17.4 Martian Meteorites: An Added Dimension	303	Suggestion for Further Reading	318
17.5 Integration and Synthesis	306	References	318
17.5.1 Pre-Noachian Period	307	Glossary	320
17.5.2 Noachian Period/System	308	Index	327

Preface: Geologic Processes in the Solar System



When we explore other worlds, what once seemed the only way a planet could be turns out to be somewhere in the middle range of a vast spectrum of possibilities. . .

Carl Sagan, 1995, Pale Blue Dot: A Vision of the Human Future in Space

When one world is not enough.

Motto of the Geological Society of America's Planetary Geology Division

Planet Earth has always been the geoscientist's laboratory. Now, though, after decades of planetary exploration, geoscientists recognize that our own world is but a singular grand experiment, and that other planets afford opportunities to examine nature's geologic experiments run with different starting compositions and under varying conditions. What used to be considered a part of astronomy now rightly belongs to geology. This substantial shift of scientific real estate has greatly expanded geology's reach, as distant points of light have been transformed into worlds shaped by more-or-less familiar geologic processes.

This book focuses on geologic processes on the planets, moons, and smaller bodies (asteroids, comets) of the Solar System. These processes are revealed and understood through exploration by orbiting or flyby spacecraft, landers and rovers, and, in the case of the Moon, by astronauts. Much of planetary geoscience involves remote sensing – visible observations, as well as measurements that use other parts of the electromagnetic spectrum ranging from gamma rays to radio waves. The application of geochemical and geophysical methods and numerical models also play significant roles. And, as in terrestrial geology, extraterrestrial samples analyzed in the laboratory constrain and quantify planetary geologic processes.

The book begins with a Grand Tour, an overview of the geologic bodies in the Solar System. Rather than taking the traditional approach of stepping outward planet by planet, we consider the temporal history of Solar System exploration in the spacecraft era and the critical role that has been played by geoscience.

Of necessity, planetary geoscientists often employ different tools than those used by geologists on Earth. Some

of these will be familiar to geology students, but with different twists.

- **Imaging and spectroscopy:** The principles of visible/ultraviolet, near-infrared/ thermal infrared, X-ray, gamma ray, neutron, and radio spectroscopy are introduced, focusing on what kinds of data are provided by remote-sensing measurements at various wavelengths and how they are interpreted.
- **Geochronology:** The application of stratigraphic principles and crater density measurements provide the means of determining the relative ages of planetary surfaces, supplemented by radiometric dating of samples, where available, for absolute age determinations.
- **Geologic mapping:** We will see how spacecraft images are obtained and used to identify and map stratigraphic, structural, and geomorphic features, and how geologic mapping techniques at different spatial scales are complemented by remote sensing data.
- **Geophysical methods:** Topography, gravity, magnetics, and seismic data, as well as density and moment of inertia, are used to probe the unseen interiors of planets, along with numerical simulations and thermal evolution models.
- **Laboratory analysis of planetary materials:** Various kinds of directly sampled extraterrestrial materials are available for petrologic and geochemical analyses in the laboratory, and the laboratory has now been carried into the field by landed spacecraft.

Following chapters on the toolkits used by planetary geoscientists, the bulk of the book focuses on processes, which are introduced wherever possible through first principles. Each chapter begins with an overview and ends with a set of questions intended to provide the student with an opportunity to review important concepts and integrate what they have learned into a broad understanding of planetary geoscience. The subject matter follows this structure:

- **Cosmochemical processes** explain the origin of elements and isotopes as the building blocks of planets and how

they were processed and fractionated in the early solar nebula.

- Observations and models help us understand the process of planetary accretion, as well as early collisional processes and orbital evolution.
- To understand planetary thermal evolution, we consider available heat sources and the resulting processes of melting and global differentiation.
- Modeling of planetary interiors requires an understanding of minerals stable at high pressures and temperatures, and how these phases are distributed.
- Planetary geodynamic processes are driven by gravity, heat flow, fluid mechanics, and rheology.
- Planetary tectonic processes differ on bodies with active versus stagnant lids.
- Igneous processes everywhere include magma generation, emplacement, and crystallization, but compositional and tectonic differences among planets yield varying results.
- Impact cratering is not a familiar process, so we consider crater mechanics, explore the geology of craters, and describe shock metamorphism.
- Some planets and many smaller bodies have volatiles sequestered in atmospheres, oceans (often subsurface), and ices.
- Wind-driven processes on bodies with atmospheres produce distinctive erosional and depositional landforms.
- The surfaces of some planets have been shaped by flowing and ponded water and other liquids.
- Physical and chemical weathering produce surficial regoliths and sedimentary deposits; aqueous alteration and thermal metamorphism affect rocks in the interiors of planets and asteroids; and mass wasting modifies planetary surfaces.
- For the emerging field of astrobiology, we review biological requirements and planetary habitability, and consider how life might be detected and how it influences a planet's evolution.

- A case study illustrates how all these kinds of information can be integrated into an understanding of the geologic processes that have shaped the evolution of a planet, in this case Mars.
- We end with an epilogue briefly exploring the diversity of exoplanets recently discovered around other stars, speculating about geologic processes on them.

The intended audience for this book is the undergraduate geology major, who already has had some exposure to mineralogy and petrology, sedimentology and stratigraphy, structure and tectonics, geochemistry, and geophysics. We provide limited background in these subjects as we go along, but some prior geologic coursework is assumed. For a decade, we have taught this course to geology majors at the University of Tennessee, and this experience has shaped our views of how to present this subject. However, we have been frustrated that a textbook focused on geoscience has not been available. Our goal is to help promote the integration of planetary geoscience into the undergraduate geology curriculum, by exploring the generality of geologic processes on other bodies. Although only a modest number of professional geologists actually work in planetary geoscience, ongoing planetary exploration has proved to be a powerful means of motivating the next generation of scientists and engineers.

We hope you will enjoy and learn from this foray into planetary geoscience, and come to appreciate that, although some of the tools may differ, the tried-and-true methods of geology work on other worlds too.

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